

# **THE RESULT OF HOT EXHAUST GAS RECIRCULATION (EGR) ON THE PERFORMANCE AND EMISSION CHARACTERISTICS OF DIESEL ENGINE WITH PALM OIL METHYL ESTER**

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## **ABSTRACT**

Transesterified fuels (biodiesel) from vegetable oils are alternative fuels for diesel engines. They are renewable and offer potential reduction in CO and HC emissions due to higher O<sub>2</sub> contents in vegetable oil. Many research studies have reported that exhaust from biodiesel fuel has higher NO<sub>x</sub> emissions while HC and PM emissions are significantly lower than operated with diesel fuel. The aim of the present investigation is to reduce NO<sub>x</sub> emissions. Exhaust gas recirculation (EGR) is one of the most effective techniques for reducing NO<sub>x</sub> emissions in compression ignition engines. A Single cylinder four stroke water cooled direct injection (DI) diesel engine was used for conducting test with (Palm methyl ester: PME) biodiesel blends with diesel fuel combined with EGR technique. The results showed that for a 7.5kW power output, B10 and B20 PME with 8% EGR rate produce less NO<sub>x</sub> emissions compared to diesel fuel for the same level smoke emissions.

**KEYWORDS:** Diesel Engine, EGR, Palm Methyl Ester, NO<sub>x</sub>, Pollution

## **INTRODUCTION**

Compression ignition engine are preferred prime movers due to excellent drivability and higher thermal efficiency. Despite their advantages they produce higher levels of NO<sub>x</sub> and smoke emissions which will more harmful to human health. Hence stringent emission norms have been imposed. In order to meet the emission norms and also the fast depletion of petroleum oil reserves lead to the research for alternative fuels for diesel engines. Biodiesel from vegetable oils are alternative to diesel fuel for diesel engines. The use of biodiesel in diesel engines does not require any engine modification. Biodiesel gives considerably lower emissions of PM, carbon monoxide (CO) and hydrocarbon (HC) without any fuel consumption or engine performance penalties. Many researchers have found that with biodiesel fueled engine produces higher NO<sub>x</sub> emissions compared to diesel [9-14]. To achieve reductions in NO<sub>x</sub> emissions, exhaust gas recirculation (EGR) can be used with biodiesel in the diesel engines. EGR is an effective technique of reducing NO<sub>x</sub> emissions from the diesel engine exhaust [1-4]. Controlling the NO<sub>x</sub> emissions primarily requires reduction of in-cylinder temperatures [2, 3]. However, the application of EGR results in higher fuel consumption and emission penalties, also EGR increases HC, CO, and PM emissions along with slightly higher specific fuel consumption [13]. EGR rates are sufficient for high load, also as the load increases, diesel engines tend to generate more smoke because of reduced oxygen.

Therefore, EGR, although effective to reduce NO<sub>x</sub>, further increases the smoke and PM emissions [5]. Abd-Alla et al [1] performed experiments on a 9.0 kW rated power dual fuel (gaseous fuel- methane with diesel as pilot fuel) mode direct injection diesel engine to study the effect of inlet air temperature by the way of mixing of hot EGR and addition of diluents gas such as CO<sub>2</sub> and N<sub>2</sub>. They reported that the addition of CO<sub>2</sub> gas in the intake charge resulted in moderate reduction of NO<sub>x</sub> emission but Unburnt hydrocarbon emission (UBHC) was increased. By increasing the intake charge temperature resulting in increase of NO<sub>x</sub> emission with decrease in UBHC, the brake thermal efficiency and power output increased due to reduced ignition delay. Also they suggested that the performance was improved at low load condition when the intake air temperature was increased. Deepak Agarwal et al [2] conducted a test on a single cylinder DI diesel engine and measured the performance and emission characteristics with rice bran methyl ester (RBME) and its blends as fuel with EGR system. They optimized and reported that 20% biodiesel blends with 15% EGR produce the less NO<sub>x</sub>, CO and HC emissions and also improved thermal efficiency and reduced BSFC.

Hountalaous et al [3] using 3D-multi dimensional model to examine the effect of EGR temperature on a turbocharged DI diesel engine with three different engine speeds, and they reported that high EGR temperature affects the engine brake thermal efficiency, peak combustion pressure, air fuel ratio and also soot emissions, and the combined effect of increased temperature and decreased O<sub>2</sub> concentration resulted low NO<sub>x</sub> emissions. Also they suggested that EGR cooling is necessary to retain the low NO<sub>x</sub> emissions and prevent rising of soot emissions without affecting the engine efficiency at high EGR rates. Ken Satoh et al [4] investigated on a naturally aspirated single cylinder DI diesel engine with various combinations of EGR, fuel injection pressures, injection timing and intake gas temperatures affect exhaust emissions and they found that NO<sub>x</sub> reduction ratio has a strong correlation with oxygen concentration regardless of injection pressure or timing. NO<sub>x</sub> reduction ratio is in direct proportion to intake gas temperatures. EGR may adversely affect the smoke emission because it lowers the average combustion temperatures and reduces the oxygen intake gases, which in turn keeps soot from oxidizing. Also they suggested that for a given level of oxygen concentration the cooled EGR reduces more NO<sub>x</sub> with less EGR rates than does at hot EGR. Nurun Nabi et al [6] reported that NO<sub>x</sub> emission was slightly lower and CO emission almost identical or slightly lower for 15% NOME blends than that of neat diesel for every EGR rate. Pradeep and Sharma et al [7] have studied performance of a single cylinder DI diesel engine with Jatropha oil methyl ester biodiesel (JBD) with hot EGR. They optimized 15 % EGR gave the adequate reduction of NO<sub>x</sub> emission with minimum possible smoke, CO, UBHC emissions. And further increased EGR rates produced more NO<sub>x</sub> emissions. Saravanan et al [8] performed a series of test on a single cylinder water cooled DI

Diesel engine with hydrogen was used as dual fuel mode with EGR technique and their results showed increase in brake thermal efficiency and lowered smoke level, particulate and NO<sub>x</sub> emissions due to absence of carbon in hydrogen fuel. Rajan and Senthil kumar et al [14] have studied twin cylinder water cooled DI diesel engine with sunflower methyl ester blends with hot EGR. They performed experiments on 15% EGR and their results showed increase in brake thermal efficiency, brake specific fuel consumption and reduction in CO, HC and NO<sub>x</sub> emissions compared to diesel.

The main objective of the present research is to investigate the effect of exhaust gas recirculation with Palm methyl ester (PME) blends and diesel fuel and also is to investigate the emissions and performance of a diesel engine with biodiesel as fuel. For this experimental study, 8 % EGR has been taken for analysis.

## EXHAUST GAS RECIRCULATION

Figure 1 shows the exhaust gas recirculation (EGR) set up in the test engine used for controlling the NO<sub>x</sub> emissions. EGR is an effective technique of reducing NO<sub>x</sub> emissions from the diesel engine exhaust. EGR involves

replacement of oxygen and nitrogen of fresh air entering in the combustion chamber with the carbon dioxide and water vapour from the engine exhaust. The recirculation of part of exhaust gases into the engine intake air increases the specific heat capacity of the mixture and reduces the oxygen concentration of the intake mixture. These two factors combined lead to significant reduction in NO<sub>x</sub> emissions. EGR (%) is defined as the mass percentage of the recirculated exhaust (MEGR) in total intake mixture (Mi).

$$\% \text{ EGR} = \frac{\text{Mass of air admitted without EGR} - \text{Mass of air admitted with EGR}}{\text{Mass of air admitted without EGR}}$$

## EXPERIMENTAL SETUP

The engine used in this experiments was a single cylinder four stroke water cooled, NA, DI diesel engine coupled with mechanical loading. A digital AVL-444 five gas analyzer is set up to find the emission characteristics of the engine. Instrumentation is provided for the measurement of fuel consumption and load on brake drum. The arrangement of experimental set up is shown in figure 1. The specifications of the test engine is given in Table 1. The experiment was conducted with conventional diesel fuel, and palm methyl ester (PME).The properties of the diesel fuel and palm methyl ester are shown in Table 2.

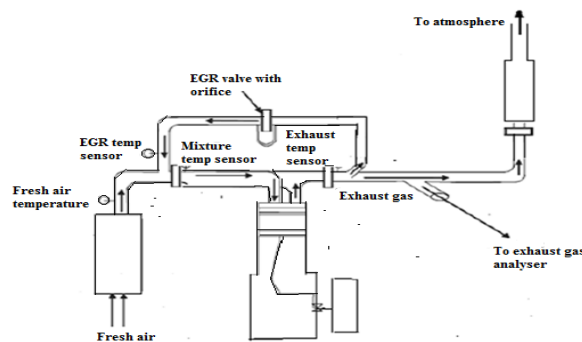


Figure 1: Experimental Setup Using EGR

Table 1: Engine Specifications

Make	Topland
Engine	Four stroke Single cylinder
BHP	5HP
RPM	1500
Fuel	Diesel
Bore	80mm
Stroke length	110mm
Starting	Cranking
Working Cycle	Four stroke
Method of Cooling	Water cooled
Method of Ignition	Compression Ignition

Table 2: Properties of Diesel and Palm Methyl Ester

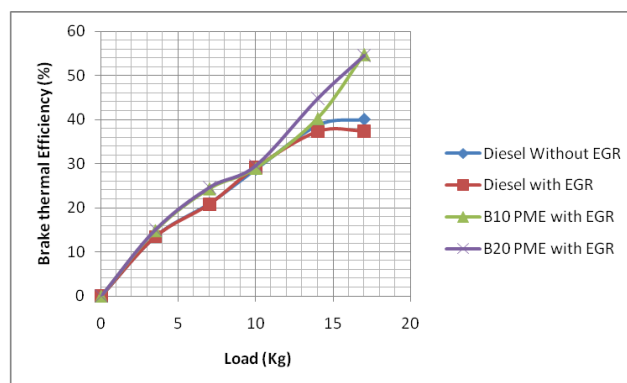
Property	Diesel	PME
Kinematic Viscosity at 38 <sup>0</sup> C (mm <sup>2</sup> /s)	2.7	4.5
Density (Kg/m <sup>3</sup> )	840	855
Calorific value (MJ/Kg)	42.5	41.3
Flash Point ( <sup>0</sup> C)	52	174
Cetane Number	47	53

## RESULTS AND DISCUSSIONS

Engine tests were carried out using diesel at 1500 rpm and different EGR rates in order to study the effect of EGR on the smoke density and  $\text{NO}_x$  concentration in the exhaust emissions. Higher amount of smoke in the exhaust is observed when the engine is operated with EGR compared to without EGR. Smoke emissions increases with increasing engine load and EGR rates. EGR reduces availability of oxygen for combustion of fuel, which results in relatively incomplete combustion and increased formation of PME and reducing  $\text{NO}_x$  emissions from diesel engine. Using biodiesel in diesel engine, smoke is decreased with increase in  $\text{NO}_x$ . Thus, biodiesel with EGR can be used to reduce  $\text{NO}_x$  and smoke intensity simultaneously. A series of exhaustive engine test were carried out which levels, an optimum of 8% EGR can be used with B20 and B10 PME of biodiesel. The performance and emission data were analyzed for thermal efficiency,  $M_{fc}$ , HC, CO,  $\text{O}_2$  in exhaust gases for  $\text{NO}_x$

## PERFORMANCE ANALYSIS

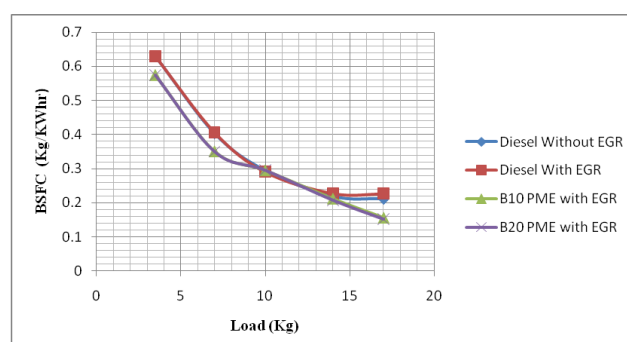
### Brake Thermal Efficiency



**Graph 1: Variation of Brake Thermal Efficiency with Load**

Graph 1 shows the variations of brake thermal efficiency of diesel and palm methyl ester blends (PME) with and without EGR. It is observed that from the figure the brake thermal efficiencies are increased with increase in load with EGR at lower load due to re-burning of hydrocarbons that enter in to the combustion chamber with the recirculated exhaust gases and at full load operation the brake thermal efficiency not affected by exhaust gases. The brake thermal efficiencies are improved with increasing concentration of bio diesel and its diesel blends due to the higher oxygen present in the bio diesel. B20 PME, B10 PME with 8% EGR show 10% and 7% increase in brake thermal efficiency at lower loads compared to diesel without EGR

### Brake Specific Fuel Consumption (BSFC)



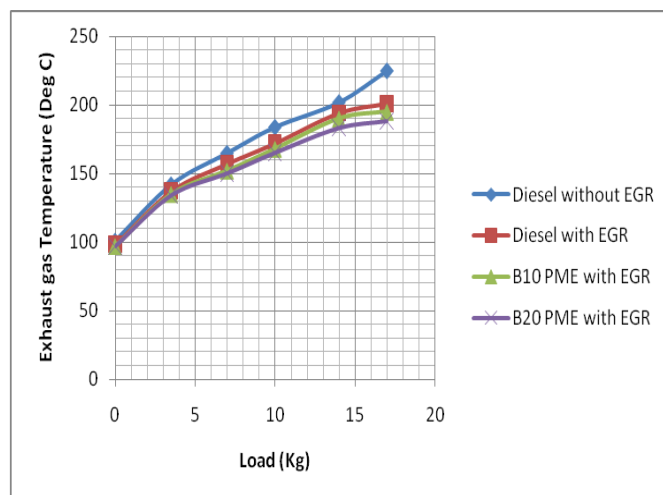
**Graph 2: Variation of BSFC with Load**

Graph 2 shows the variations of BSFC for diesel and biodiesel blends with and without EGR. The brake specific

fuel consumptions for diesel are almost similar at lower loads when engine is operated with EGR compared to without EGR. However, at higher engine loads, the brake specific fuel consumptions with EGR are higher to that of without EGR for diesel fuel. The brake specific fuel consumptions are decreased with increasing concentration of biodiesel blends when the engine is operated on biodiesel blends with EGR due to lower calorific value and high viscosity of the sunflower methyl ester when compared to diesel with and without EGR. The brake specific fuel consumptions are decreased about 11 % for B10 and 12.5 % for B20 palm methyl ester blends with EGR.

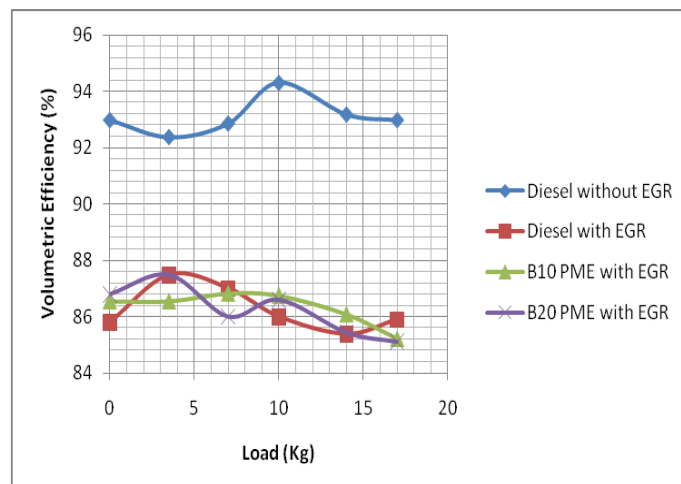
### Exhaust Gas Temperature

Graph 3 shows the variations of exhaust gas temperature with diesel and blends of biodiesel with EGR. It can be observed that with increase in load, exhaust gas temperature also increases. The exhaust gas temperature was found to be lower for EGR operated engine with diesel due to lower availability of oxygen for combustion and higher specific heat of intake exhaust gas air mixture. The temperature of the exhaust gases for B10 and B20 palm methyl ester were observed lower than the diesel without EGR.



Graph 3: Variation of Exhaust Gas Temperature with Load

### Volumetric Efficiency



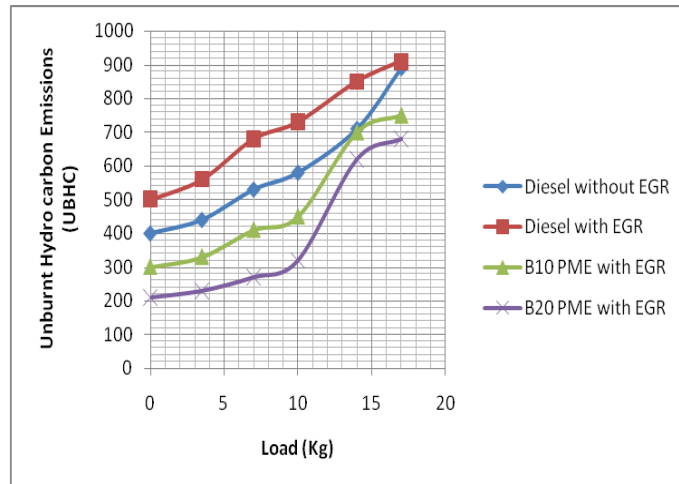
Graph 4: Variation of Volumetric Efficiency with Load

Graph 4 shows that variation of volumetric efficiency of the engine at different loads it was to found that the volumetric efficiency is lower for EGR operated engine with diesel and biodiesel blends due to high specific heat of intake exhaust gas in mixture. The volumetric efficiencies of Biodiesel blends are almost similar to diesel using EGR.

The volumetric efficiencies for diesel and biodiesel blends at loads with 8% EGR are lower than diesel without EGR.

## EMISSION CHARACTERISTICS ANALYSIS

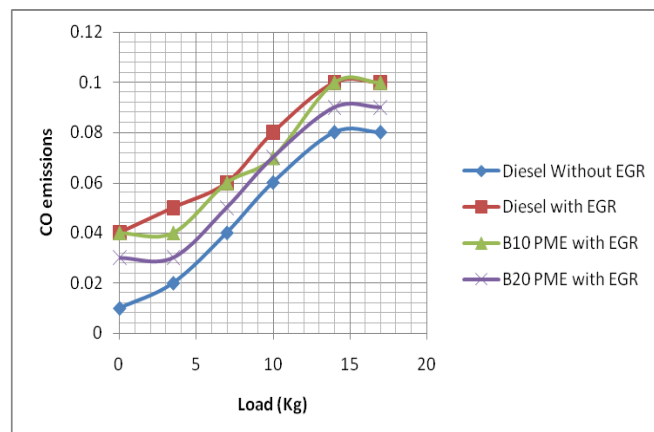
### Un-Burnt Hydro Carbon Emissions (UBHC)



**Graph 5: Variations of Hydrocarbon Emission with Load**

Graph 5 shows the variations of UBHC emissions of diesel and palm methyl ester blends with and without EGR. The UBHC increases with increase in load and EGR rate. because of lower oxygen content available for combustion, that is lower excess oxygen concentration results rich mixture which results incomplete combustion and results higher hydro carbon emission. It is also observed from the graph the 10% and 20%biodiesel blend with 8% EGR gives 30% and 45 % lower UBHC emissions compared to diesel with EGR.

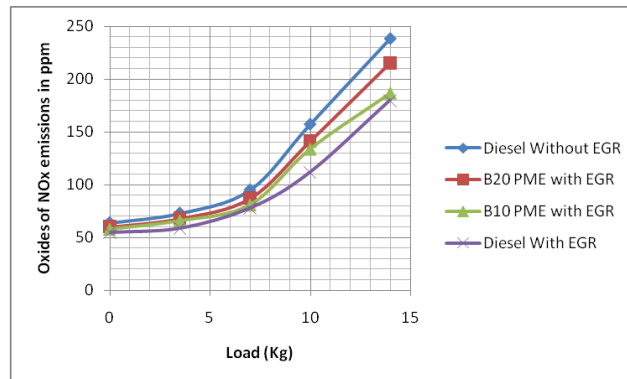
### Carbon Monoxide Emissions (CO)



**Graph 6: Variations of CO Emissions with load**

Graph 6 shows the variations of CO emissions of diesel and palm methyl ester with EGR and without EGR. The CO increases with increase in load and EGR rate. However, CO emissions of PME were comparatively lower. Higher values of CO were observed at loads for both diesel and biodiesel fuels with EGR. For biodiesel, the excess oxygen content is believed to have partially compensated for the oxygen deficient operation under EGR. Dissociation CO<sub>2</sub> to CO at peak loads where high combustion temperatures and comparatively fuel rich operation exists, can also contribute to higher CO emissions. It is observed that from the graph CO emissions are 8% and 25% lower for B10and B20 biodiesel blends respectively compared with diesel when the engine is operated with EGR.

### Nitrogen Oxides Emission (NO<sub>x</sub>)



**Graph 7: Formation of NO<sub>x</sub> Emissions with Load**

Graph 7 shows the variations of NO<sub>x</sub> emissions of diesel and Palm oil methyl ester with and without EGR. The degree of reduction in NO<sub>x</sub> at higher at higher loads. The reasons for reduction in NO<sub>x</sub> emissions using EGR in diesel engines are reduced oxygen concentration and decreased the flame temperatures in the combustion chamber. However, NO<sub>x</sub> emissions in case of biodiesel blends without EGR are higher than diesel due to higher temperatures prevalent in the combustion chamber. It is also observed from the graph the 10 % and 20 % biodiesel blends have 15 % and 10 % lower NO<sub>x</sub> emissions respectively when compared to diesel fuel without EGR.

### CONCLUSIONS

In this report the performance and emission characteristics of diesel fuel and PME blends with exhaust gas recirculation were investigated. The results of this study may be summarized as follows:

- The brake thermal efficiency was increased to 7% when engine is operated with biodiesel blends (B10) of 8% EGR compared to diesel without EGR.
- The Brake Specific fuel consumption (BSFC) was decreased to 11% due to lower calorific value of the biodiesel when engine is operated with biodiesel blends (B10) of 8% EGR compared to diesel without EGR.
- The volumetric efficiency was reduced due to high specific heat of gases when engine is operated with EGR compared to without EGR
- The total unburnt HC and CO emissions were decreased by 30% and 8% for 10% biodiesel blends respectively compared to diesel fuel with EGR and smoke emissions were observed as increases, due to incomplete combustion.
- Compared with conventional diesel fuel, the exhaust NO<sub>x</sub> was reduced about 15% at 10 % biodiesel blends with 8% EGR due to less oxygen available in the recirculated exhaust gases which lowers the flame temperature in the combustion chamber.

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